# Ocean heat effect on the observed and predicted reduction of the Arctic sea ice: results of the AARI contribution to ACCESS WP1


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**RESULTS:**
- Atlantic Water plays significant role in ice melting in the region between Svalbard and Franz Joseph Land
- Upward heat flux from AW layer due to turbulent mixing and 'double diffusive' convection is the strongest over the continental slope
- Under conditions of decreased summer ice cover lateral/bottom ice melting is expected to intensify

## Background

Under conditions of reducing ice cover the influence of ocean heat on Arctic sea ice is expected to increase. We are identifying several ways how the ocean heat may be transferred towards the ice contributing to the existent ice thinning and/or impeding new ice formation. They include:

- Direct impact of sensible heat, stored in the ocean on the ice cover in the locations close to the warm inflow of Atlantic Water (AW) and Pacific Water (PW);
- Vertical heat flux via double diffusion convection from AW layer in the central Arctic Basin
- Increased upward heat flux from AW over continental slope and outer shelf, where AW upwells the shelf, and vertical mixing is enhanced due to strong shear, tidal currents, and shelf intrusions;
- Atmospheric heat accumulation in the melted water, which enhances lateral ice erosion.

## Atlantic Water influence on sea ice in the inflow region

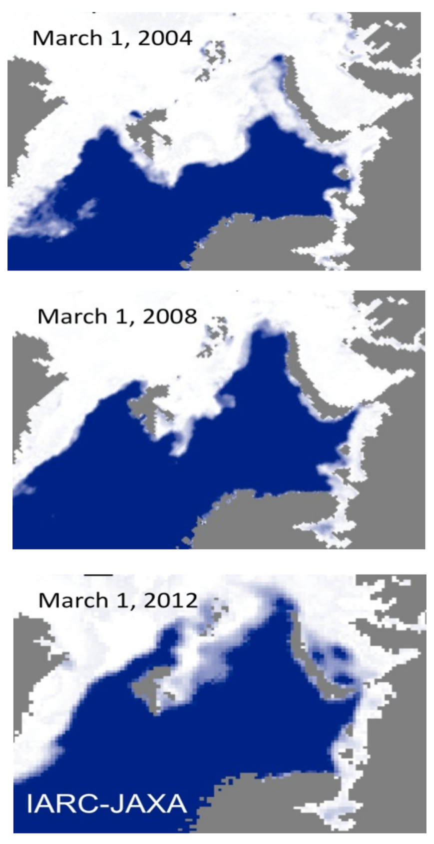


*Fig. 1. Location of ice edge (data from IARC-JAXA)*

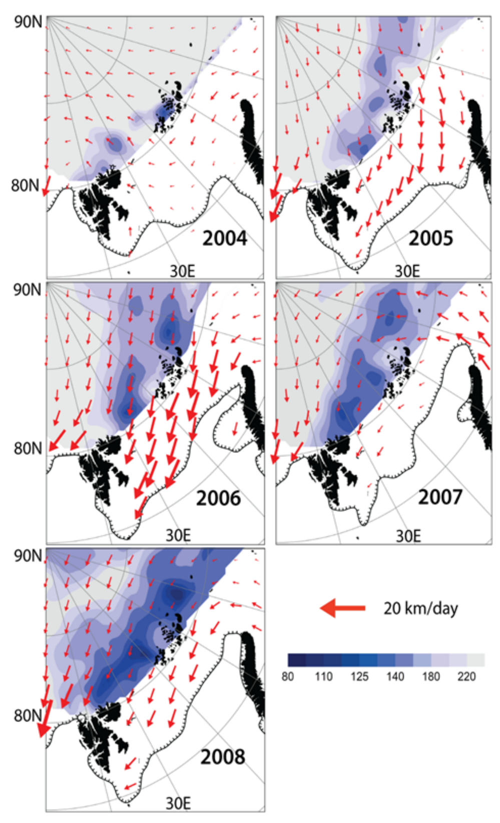


*Fig.2 Ice thickness and mean ice drift in February - March*

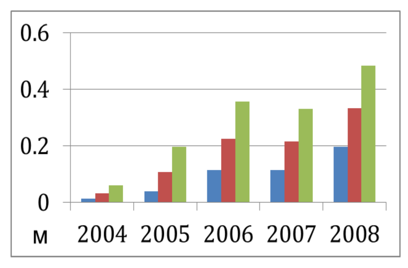


*Fig.3 Deviation of ice thickness from the mean in the Western Nansen Basin for the mean ice thickness in the range 180-220 cm*

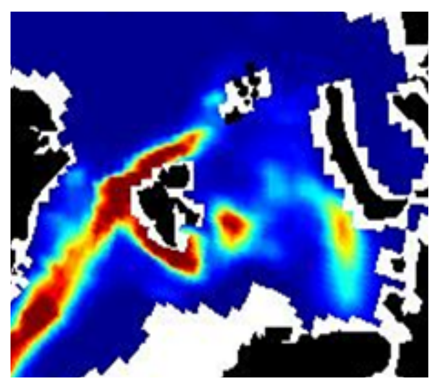

*Fig. 4. Mean ice melting from the bottom (mm/day) in February 1980-2000, (NorESM model results: L.H. Smedsrud)*

The Atlantic Water (AW) entering the Arctic through Fram Strait has often been considered less important for the ice cover than atmospheric heat and Pacific water inflow because of strong stratification in the Arctic Ocean and the deeper location of AW compared to Pacific water. In the combined examination of oceanographic measurements and satellite observations of ice concentration and thickness, we find evidence that AW has a direct impact on the thinning of arctic sea ice downstream of Svalbard Archipelago. The affected area extends as far as Severnaya Zemlya Archipelago. The imprints of AW appear as local minima in sea ice thickness; ice thickness is significantly less than that expected of first-year ice. Our lower-end conservative estimates indicate that the recent AW warming episode could have contributed up to 150-200 km$^3$ of sea ice melt per year, which would constitute about 20% of the total 900 km$^3$/yr negative trend in sea ice volume since 2004.

## Estimates of 'double-diffusive' heat fluxes in the Arctic Basin

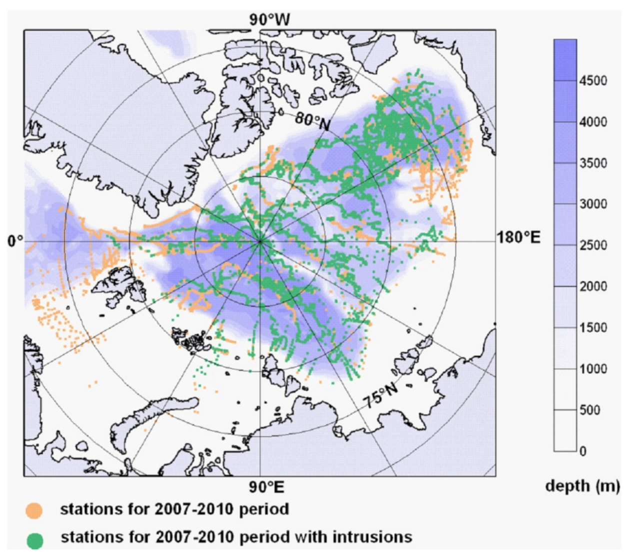


*Fig. 5. CTD- stations for 2007-2010 period*

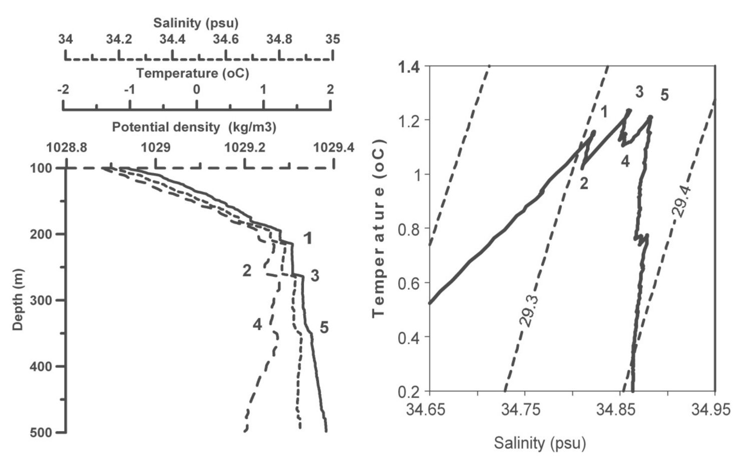


*Fig. 6. Example of 'triple pick' structure*

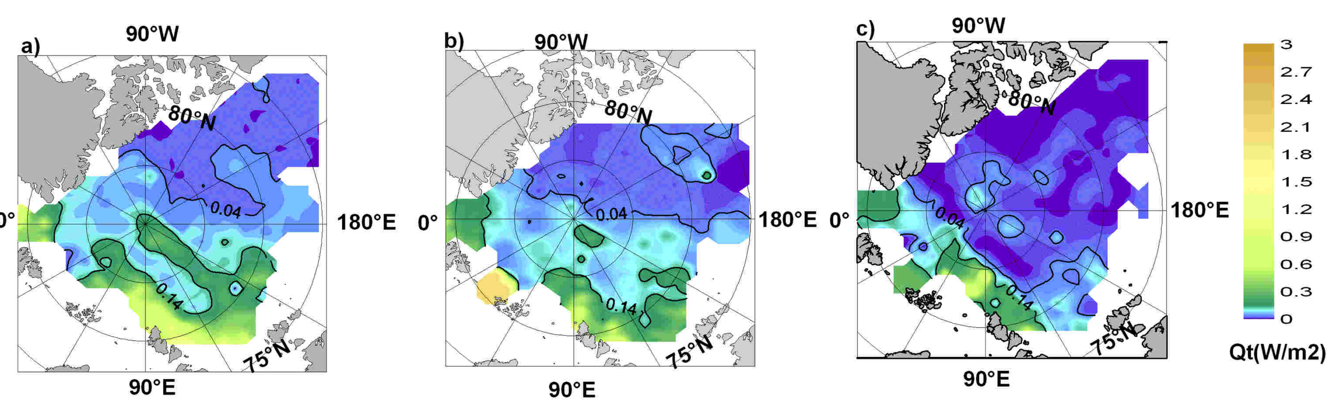


*Fig. 6. Spatial distributions of vertical heat fluxes at interfaces a) 1, b) 3, c) 5.*

CTD profiles (ITP and shipborn) carried out during 2007–2010 period (***Fig.5***) were analysed in order to study the frontal interleaving structures in the Arctic Basin. The general overview of 'double-diffusive staircase' properties have been done for different parts of the Arctic Basin. Based on the hypothesis of isopycnically coherent structures the 'triple pick' intrusive structures (***Fig.6)*** were distinguished at every CTD profile and the properties of these structures (temperature and salinity vertical gradients, density ratios, vertical scales etc.) were calculated at the interfaces and within the layers. The intensity of interleaving processes were estimated by using both vertical temperature and salinity gradients at intrusive interfaces and measure of inversions at every CTD profile. Using parametrizations of Kelly (1984) the vertical heat are estimated at the interfaces of 'triple pick' structure (***Fig.7***).

## AW warming effect at the Laptev Sea continental slope

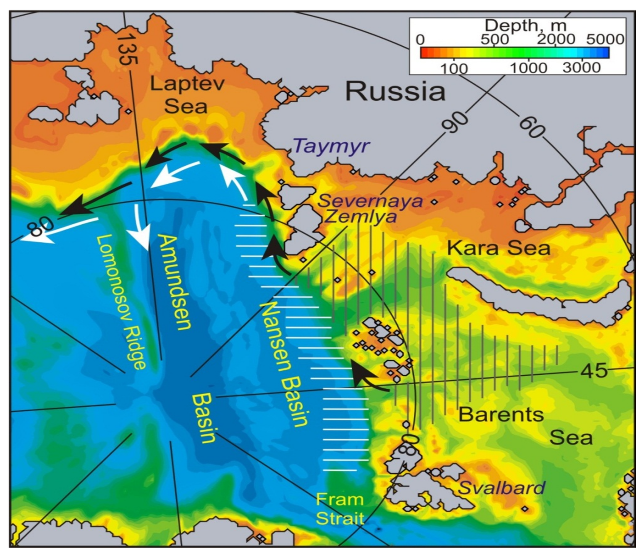


*Fig. 8. Formation area (shading) and the circulation (arrows) of the Fram Strait branch halocline (white) and the Barents Sea branch halocline (gray), according (Rudels et al., 2004).*

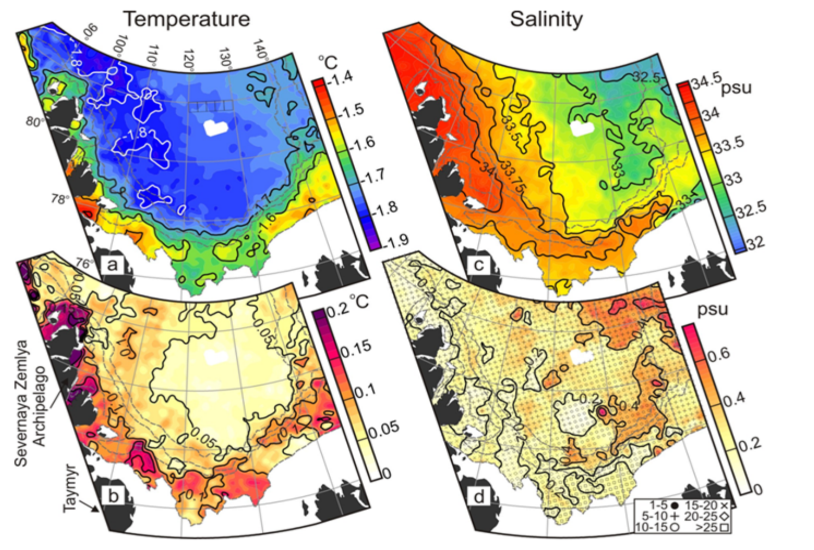


*Fig. 10. Statistics (mean and SSD) of temperature and salinity distribution in the Laptev sea (1940-2009)*

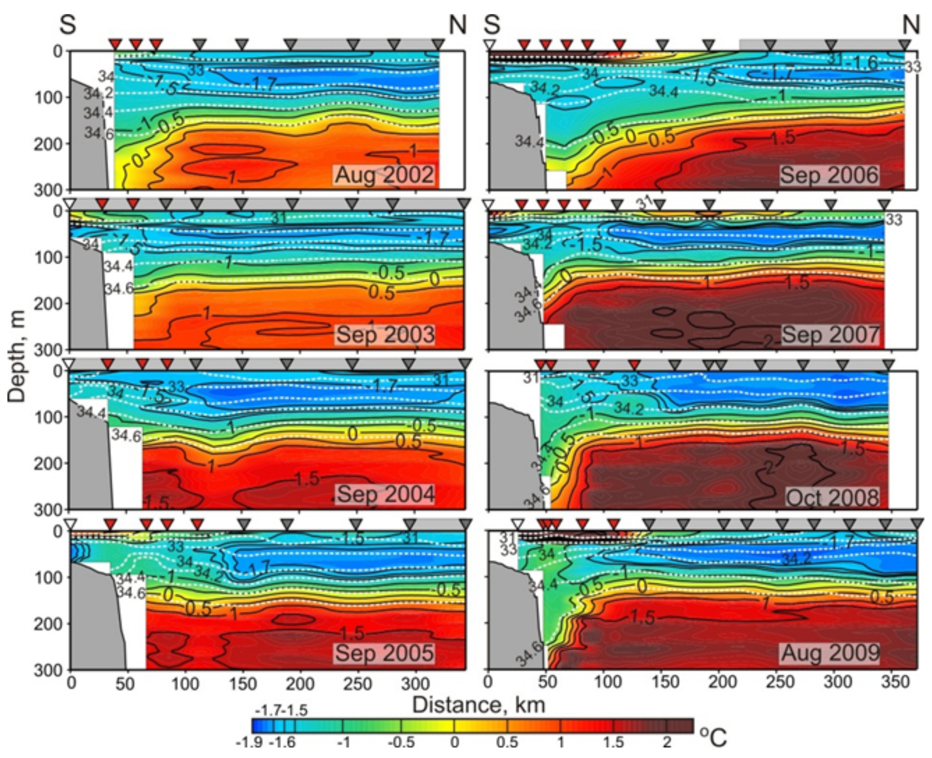


*Fig. 9. Temperature (deg.C) distribution at sequential cross-slope transect along 126$^0$ E in 2002 - 2009*

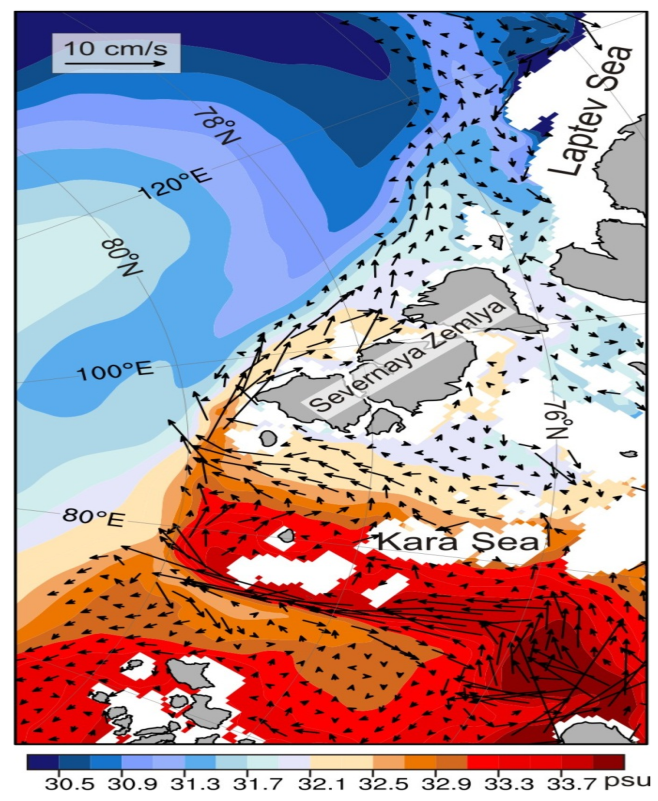


*Fig. 11. Simulated (HAMSOM model) long-term mean (1970-2009) LHW (50 m) velocity (arrows) and salinity (colour) in the Kara - Laptev seas.*

Important part of heat and salt lost from the Atlantic Water is gained by the overlaying water at the continental slope. This implies the role of intensive vertical mixing over the sloping topography, which contributes to the enhanced vertical heat/salt flux. Recent CTD-sections (***Fig.9***) and historical hydrographic data (***Fig.10***) show a distinct cross-slope difference of the lower halocline water (LHW) over the Laptev Sea continental margins. Over the slope, the LHW is on average warmer and saltier by 0.2°C and 0.5 psu, respectively, relative to the off-slope LHW. The LHW temperature time series constructed from historical records links the Laptev Sea on-slope LHW temperature to the Atlantic water (AW) boundary current transporting warm water from the North Atlantic. In contrast, the LHW salinity is linked to the sea-ice and wind forcing over the potential upstream source region in the Barents and northern Kara seas, as indicated by our hydrodynamic model results (***Fig.11***). Over the Laptev Sea continental margin, on-slope propagating saltier LHW originated from the Barents Sea favours weaker salinity stratification stronger downstream mixing with underlying AW that, in turn, contributes to enhanced vertical mixing with underlying AW.

## On the role of stratification in the near-surface layer on the lateral/bottom ice melt

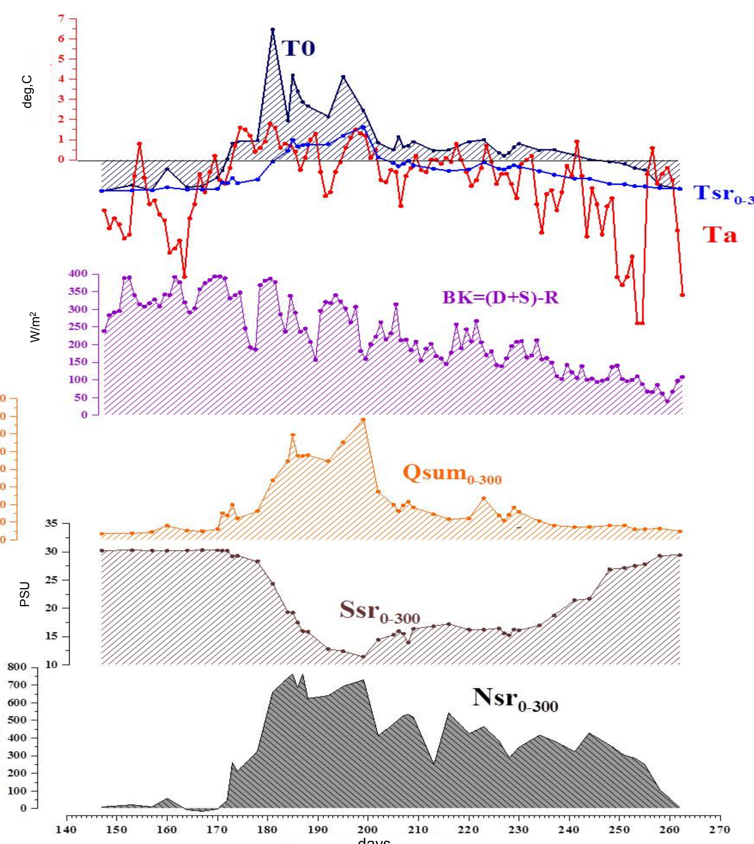


*Fig. 12. Mean parameters of the summer flaw lead: Tsr and Ssr – mean temperature and salinity within the surface 3-m layer; T0 – water temperature at the surface; Ta – air temperature; BK – radiation balance at the ice-air interface; Qsum and Ssr – heat content and mean salinity in the upper (3 m) layer; Nsr – Brunt frequency (data from NP-31).*

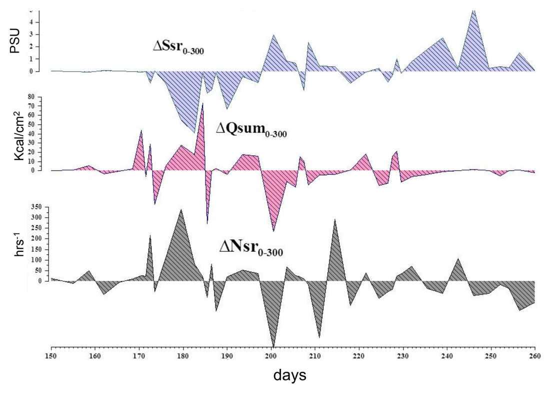


*Fig. 13. Up-time' differences of heat content (ΔQsum), mean salinity (ΔSsr) and Brunt frequency (ΔNsr) (data from NP-31).*

Before the onset of summer heating the surface water in flaw leads is at the freezing point and relatively salty (no stratification). The incoming solar radiation does not noticeably warm up this upper layer, because the heat is redistributed within the thicker (~10-15 m layer) and warms up the surrounding ice floes Rapid increase of temperature and heat content in the surface layer starts with snow and ice melting at the top and flushing of warm (~ 0 deg.C) water into the leads (Fig.1). As a result, extremely strong halocline forms at the depth of few meters. It prevents the heat, accumulated in the upper layer, from penetration into the deep. Thin surface layer rapidly gains heat from the atmosphere, and since it is in direct contact with ice floes it accelerates lateral and bottom melting. High correlation coefficients between analysed parameters confirm that suggested mechanism is valid.

## Publications


Ivanov V.V., Alexeev V.A., Repina I.A., Koldunov N.V., Smirnov A.V. Tracing Atlantic Water signature in the Arctic sea ice cover east of Svalbard // Advances in Meteorology. 2012. Vol. 2012. Article ID 201818. 11 pages doi:10.1155/2012/201818.

Dmitrenko, I. A., S. A. Kirillov, V. V. Ivanov, B. Rudels, N. Serra, N. V. Koldunov, 2012: Modified Halocline Water over the Laptev Sea Continental Margin: Historical Data Analysis. J. Climate, 25, 5556–5565.doi: http://dx.doi.org/10.1175/JCLI-D-11-00336.1

Dmitrenko, I. A., V. V. Ivanov, S. A. Kirillov, E. L. Vinogradova, S. Torres-Valdes, and D. Bauch, 2011, Properties of the Atlantic derived halocline waters over the Laptev Sea continental margin: Evidence from 2002 to 2009, J. Geophys. Res., doi:10.1029/2011JC007269



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